Overall Story

- Accelerating charges generate free space electromagnetic waves.
- Light is an EM wave and can be reflected and refracted.
- Mirrors and lenses form images of objects.

Maxwell's Equations

$$\oint \vec{\mathbf{E}}.d\vec{\mathbf{A}} = \frac{Q}{\varepsilon_0}$$

Gauss' Law

$$\oint \vec{\mathbf{B}}.d\vec{\mathbf{A}} = 0$$

Gauss' Law for Magnetism – no magnetic monopoles

$$\oint \vec{\mathbf{E}}.d\vec{\mathbf{s}} = -\frac{d\Phi_B}{dt}$$

Faraday's Law

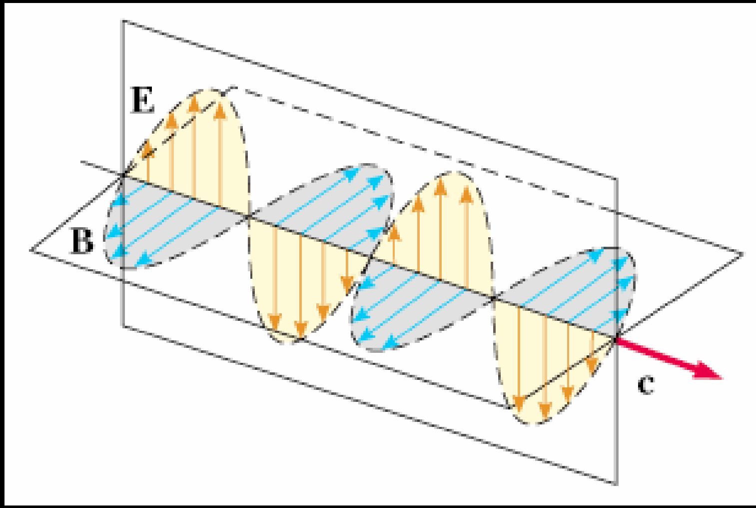
$$\oint \vec{\mathbf{B}}.d\vec{\mathbf{s}} = \mu_0 I + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$$

Ampère-Maxwell Law

$$\vec{\mathbf{F}} = q\vec{\mathbf{E}} + q\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

Lorentz Force Law

EM Waves



$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$ Speed of Light

$$\omega = 2\pi f$$ Angular Frequency

$$\lambda = \frac{c}{f}$$ Wavelength

$$k = \frac{2\pi}{\lambda}$$ Wavenumber

$$\frac{\omega}{k} = c$$

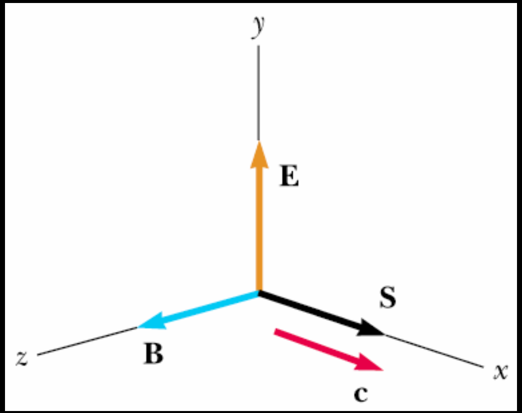
$$E = E_{\max} \cos(kx - \omega t)$$
$$B = B_{\max} \cos(kx - \omega t)$$

$$\frac{E}{B} = \frac{E_{\max}}{B_{\max}} = \frac{\omega}{k} = c$$

Energy Carried by EM Waves

$$\vec{\mathbf{S}} = \frac{1}{\mu_0}\vec{\mathbf{E}} \times \vec{\mathbf{B}}$$

Poynting Vector (W/m^2)



$$S = \frac{EB}{\mu_0} = \frac{E^2}{\mu_0 c} = \frac{c}{\mu_0}B^2$$

$$I = S_{av} = \frac{E_{max}B_{max}}{2\mu_0} = \frac{E_{max}{}^2}{2\mu_0 c} = \frac{c}{2\mu_0}B_{max}{}^2$$

$$u_E = u_B = \frac{1}{2}\varepsilon_0 E^2 = \frac{B^2}{2\mu_0}$$

$$u = u_E + u_B = \varepsilon_0 E^2 = \frac{B^2}{\mu_0}$$

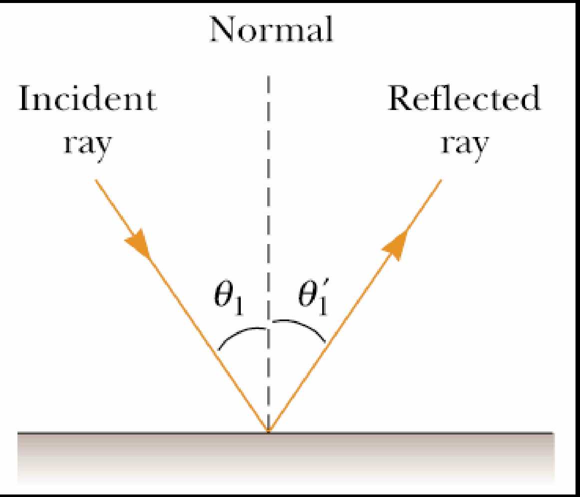
$$u_{av} = \varepsilon_0 \left(E^2\right)_{av} = \frac{1}{2}\varepsilon_0 E_{max}{}^2 = \frac{B_{max}{}^2}{2\mu_0}$$

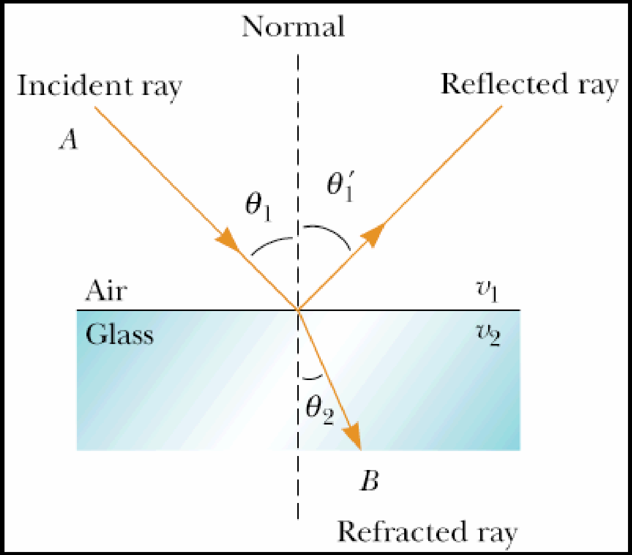
$$I = S_{av} = c u_{av}$$

Momentum and Radiation Pressure

	Momentum	Pressure
Complete Absorption	$p = \frac{U}{c}$	$P = \frac{F}{A} = \frac{1}{A}\frac{dp}{dt} = \frac{S}{c}$
Complete Reflection	$p = \frac{2U}{c}$	$P = \frac{2S}{c}$

Reflection and Refraction





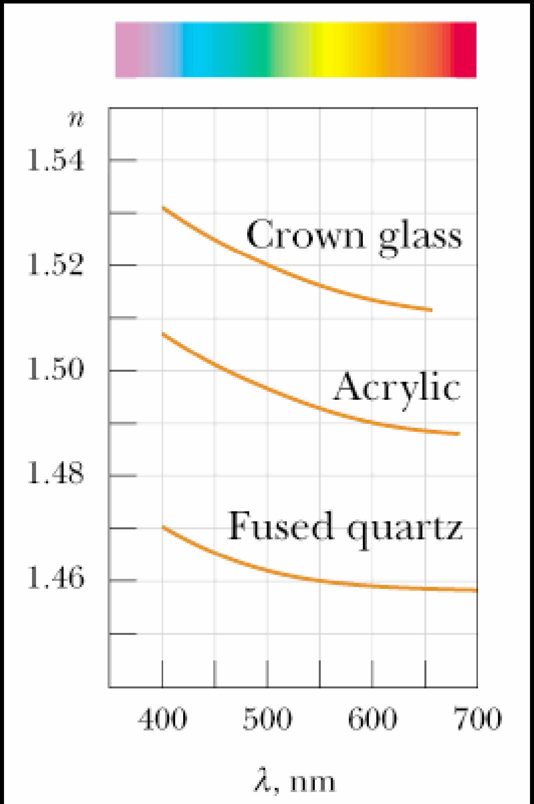
$$\theta_1' = \theta_1$$

$$n = \frac{c}{v}$$

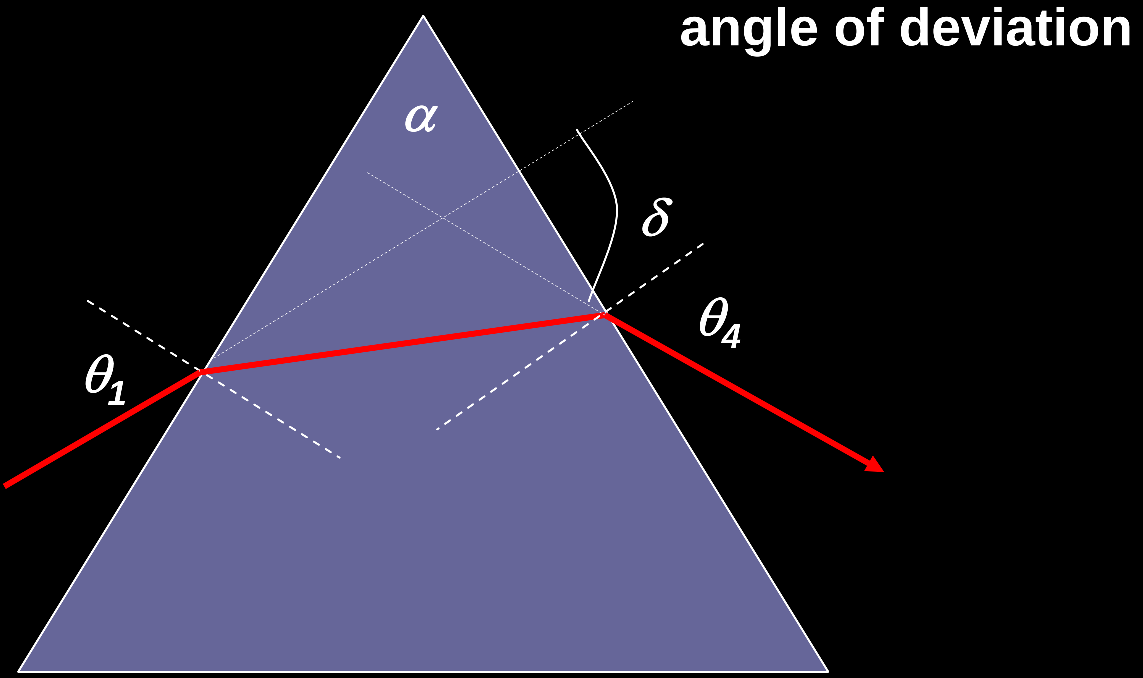
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\sin\theta_c = \frac{n_2}{n_1}$$

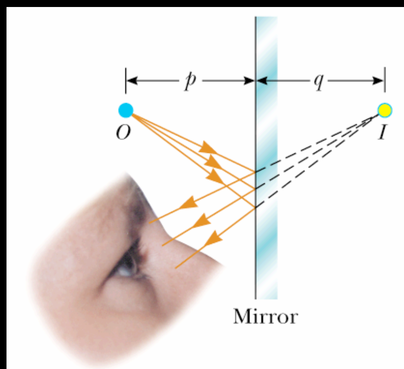
Dispersion and Prisms



$$n = n(\lambda)$$

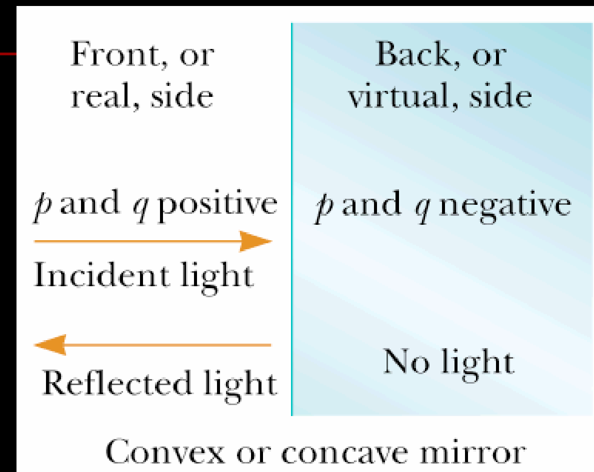


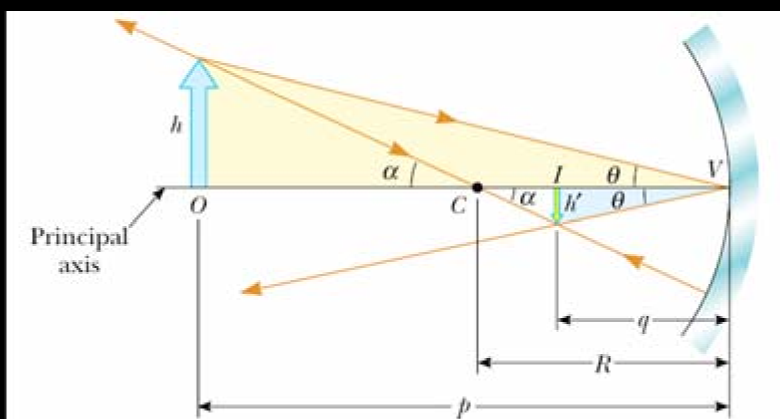
Images by Mirrors

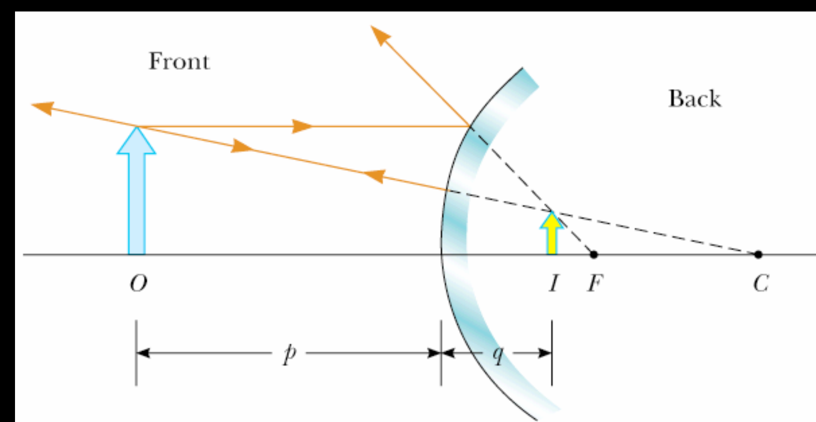


$$p = q$$

$$M = 1$$





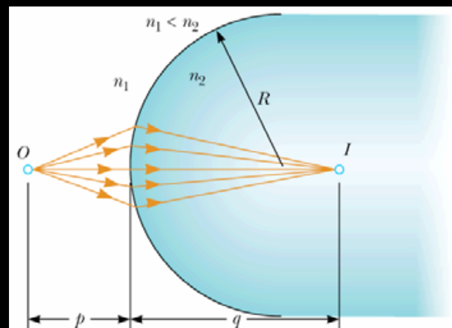


$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

$$f = \frac{R}{2}$$

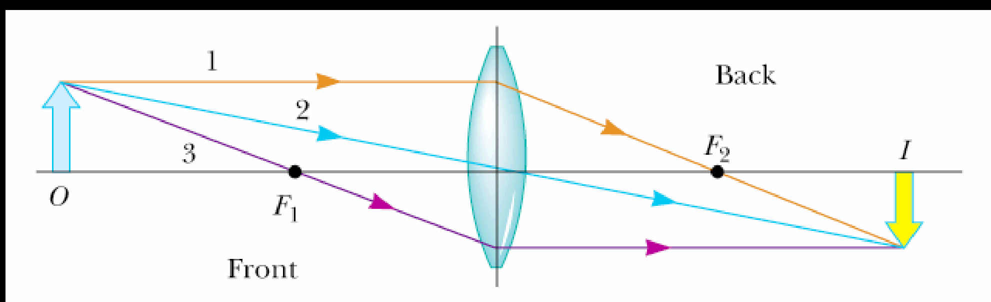
$$M = \frac{h'}{h} = -\frac{q}{p}$$

Images by Refraction and Lenses



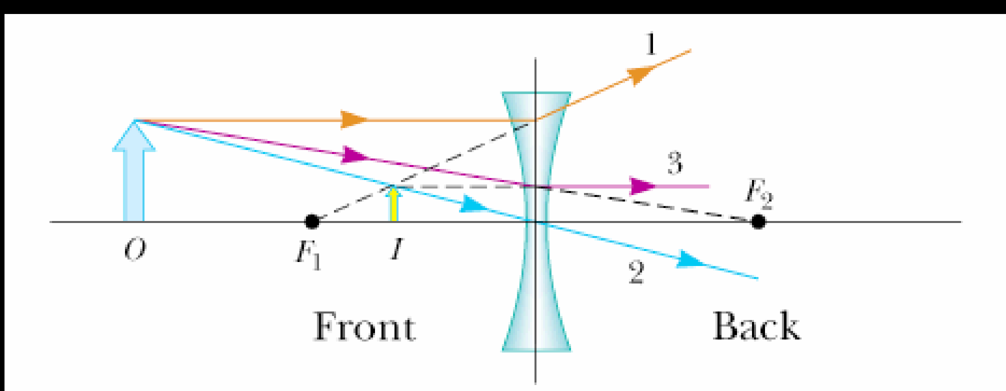
$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{(n_2 - n_1)}{R}$$

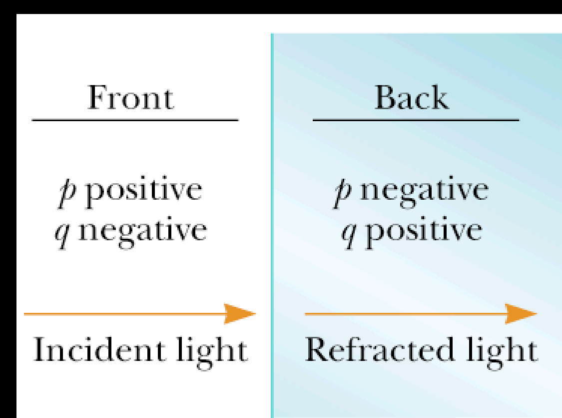
$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$



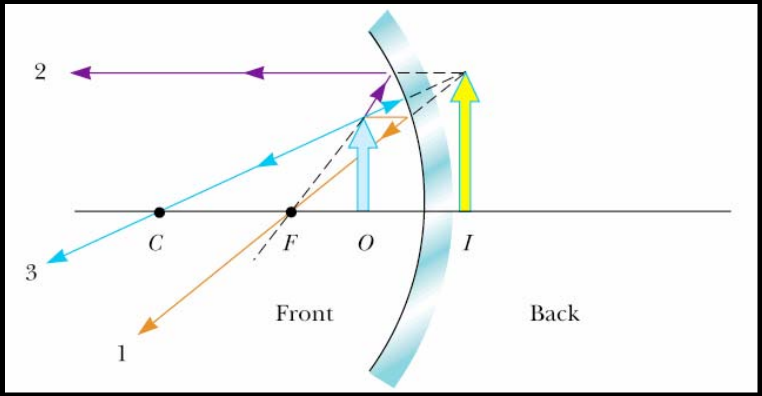
$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

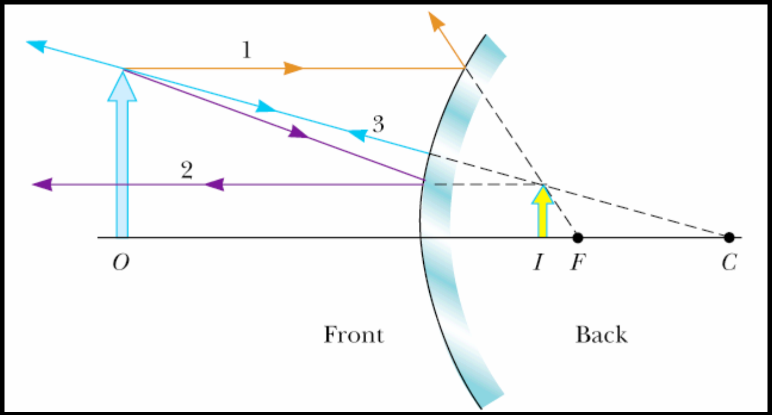
$$M = \frac{h'}{h} = -\frac{q}{p}$$

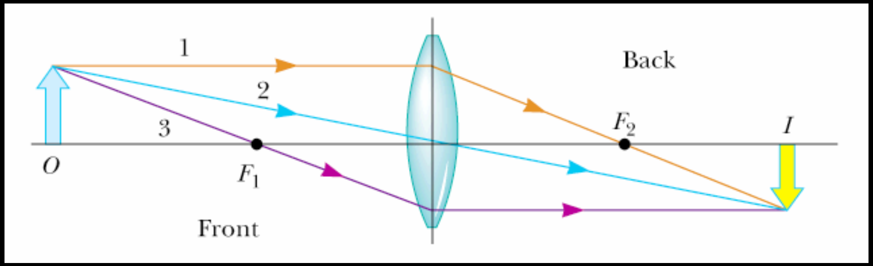


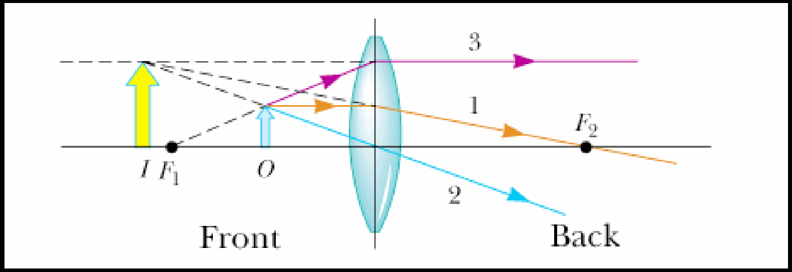


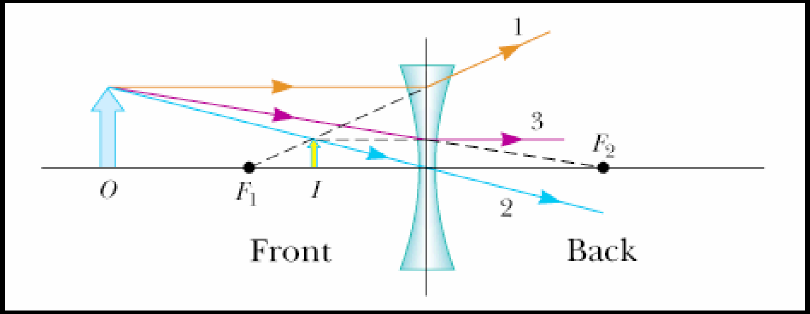
Ray Diagrams





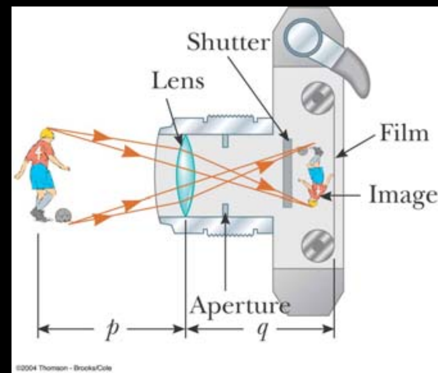






Optical Instruments

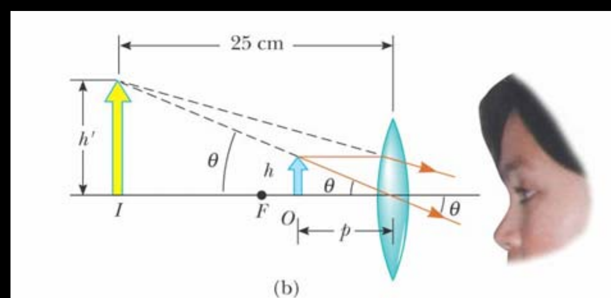
The Camera



$$I \propto D^2 / f^2$$

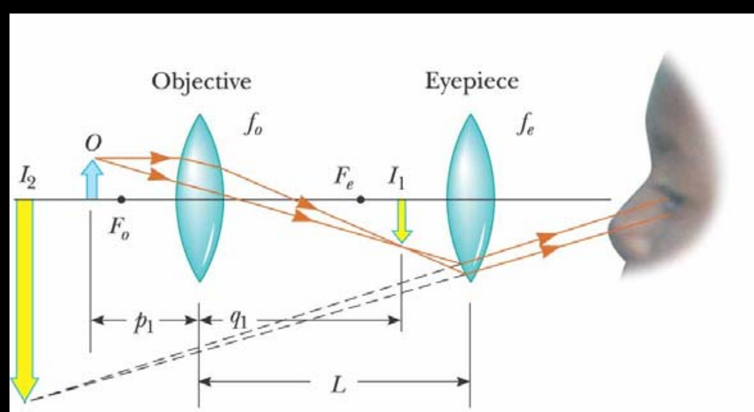
$$f-number = \frac{f}{\#} = \frac{f}{D}$$

Magnifier



$$m_\theta \approx \frac{25cm}{f}$$

Compound Microscope



$$M = -\frac{p_1}{f_o}\frac{25cm}{f_e}$$